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NACA

RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE-SPINNING-TUNNEL INVESTIGATION TO DETERMINE THE EFFECT OF SPIN-RECOVERY ROCKETS AND THRUST SIMULATION ON THE RECOVERY CHARACTERISTICS OF A 1/25-SCALE MODEL OF THE CHANCE VOUGHT XF8U-1 AIRPLANE

TED NO. NACA DE 392

By Sanger M. Burk, Jr., and Henry A. Lee

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

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SUMMARY

An investigation has been conducted in the Langley 20-foot free-spinning tunnel on a 1/25-scale model of the Chance Vought XF8U-1 airplane to determine the effect of spin-recovery rockets on the recovery characteristics of the model. The rockets were attached to the model so as to provide a yawing moment about the model center of gravity. The investigation also included tests to determine the effect of simulated engine thrust on the recovery characteristics of the model.

On the basis of model tests, satisfactory spin recoveries were indicated if an antispin yawing-moment coefficient of at least 0.08 and not greater than 0.13 was provided by either rockets attached to the wing tips or installed in the fuselage ahead of the airplane center of gravity; the yawing moment was applied for approximately 10 seconds, full scale. Simulation of engine thrust did not aid the spin recoveries and may have been slightly detrimental.

INTRODUCTION

Military airplanes generally must be spin demonstrated, and therefore must be equipped with an emergency spin-recovery device in case the controls are ineffective in producing a spin recovery or cannot be moved for recovery. Recently, interest has been evidenced in the use of rockets as an emergency spin-recovery device. The feasibility of using rockets as an emergency spin-recovery device has been indicated by results of previous investigations conducted in the Langley 20-foot free-spinning tunnel (refs. 1, 2, and 3). The results in reference 2 where a comparison was made between model and full-scale spin recoveries obtained by use of rockets indicated excellent agreement between model and full-scale tests. Therefore, at the request of the Bureau of Aeronautics, Department of the Navy, rocket spin-recovery tests which also included tests simulating the effect of engine thrust on spin recovery were conducted on a 1/25-scale model of the Chance Vought XF8U-1 airplane in the Langley 20-foot free-spinning tunnel.

The spin and recovery characteristics of this model by control manipulation is the subject of a separate investigation. In the present investigation the recovery characteristics of the model were determined by the application of a yawing moment about the Z body axis of the model produced by rockets attached to the wing tips or by rockets installed in the nose of the model. Brief exploratory tests were also made with rockets mounted on the wing tips to provide a rolling moment.

Although in the past experience has indicated, in general, that the application of a moment is essential for spin recovery, it was considered desirable to conduct additional tests to determine what effect the application of a large thrust, such as is available for present turbojet engines, would have in effecting a spin recovery by simulating the engine thrust with rockets.

SYMBOLS

An illustration of an airplane in a spin is shown in figure 1; the positive directions of the forces and moments along and about the body axes are indicated.

X longitudinal force acting along X body axis, positive forward, lb

Y lateral force acting along Y body axis, positive to right, lb

Z normal force acting along Z body axis, positive downward, lb

L rolling moment acting about X body axis, positive when it tends to lower right wing, ft-lb

M pitching moment acting about Y body axis, positive when it tends to increase angle of attack, ft-lb

N yawing moment acting about Z body axis, positive when it tends to turn airplane to right, ft-lb

C_n yawing-moment coefficient, N/qSb

q dynamic pressure, $\rho/2V^2$, lb/sq ft

S wing area, sq ft

b wing span, ft

Ω angular velocity about spin axis, radians/sec (unless otherwise indicated)

ρ air density, slugs/cu ft

V rate of descent, ft/sec

c local chord, in.

$\bar{c}$ mean aerodynamic chord, in.

$x/\bar{c}$ ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord

$z/\bar{c}$ ratio of perpendicular distance between center of gravity and thrust line to mean aerodynamic chord (positive when center of gravity is below thrust line)

W weight of airplane, lb

g acceleration due to gravity, taken as 32.2 ft/sec^2

m mass of airplane, W/g, slugs

μ airplane relative-density coefficient, $m/\rho Sb$

I_X, I_Y, I_Z moments of inertia about X, Y, and Z body axes, respectively, slug-ft^2

$\frac{I_X - I_Y}{mb^2}$ inertia yawing-moment parameter

$\frac{I_Y - I_Z}{mb^2}$ inertia rolling-moment parameter

$\frac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

ϕ angle of wing tilt (commonly called angle of bank; angle between span axis and the horizontal), positive when right wing is down, deg

T thrust of rocket, oz unless otherwise indicated

t time, sec

APPARATUS AND METHODS

Model

The 1/25-scale model of the Chance Vought XF8U-1 airplane used in the current investigation was constructed at the David Taylor Model Basin, Department of the Navy. The model was made entirely of plastic. A three-view drawing of the model with the rockets installed at various locations is shown in figure 2. A photograph of the model with the rockets installed is shown in figure 3. The dimensional characteristics of the airplane represented by the model are given in table I.

Model Rockets

The model rockets used in this investigation were designed and developed by the Langley Model Propulsion Section of the Pilotless Aircraft Research Division. The rockets are precision built and made of steel. These rockets are the initial results of a systematic program to develop various sizes of rockets for use on dynamic spin-tunnel models. The only size rocket available at present that can deliver its specified thrust is a rocket producing 3 ounces of thrust for 2 seconds. The magnitude and duration of the rocket thrust for several of these model rockets are shown in figure 4. It should be noted that the magnitude and time of the rocket firings are fairly similar and indicate good repeatability of firings. This particular size rocket has been used satisfactorily in previous spin-tunnel investigations (refs. 2 and 3). Based on the test altitude (30,000 ft) and scale of the model used in the present investigation, the thrust of this small rocket is equivalent to

1,085 pounds of thrust full scale and the corresponding full-scale thrust duration is 10 seconds. A diagrammatic sketch of this rocket and the electrical circuit is shown in figure 5. A more detailed description of this rocket is given in reference 2.

The total thrust of the engine and afterburner of the airplane in spinning attitudes is estimated by Chance Vought Aircraft, Inc., to be between 4,500 and 6,000 pounds at the approximate altitude simulated in the present tests (30,000 ft). It should be noted that, although the static-thrust rating of this particular engine (see table I) plus the afterburner is approximately 14,500 pounds, the thrust will be considerably less in spinning attitudes because the airplane will have a very high angle of attack and a low forward speed. At present a model rocket large enough to simulate the thrust of the full-scale engine and afterburner of the subject airplane in spinning attitudes is not available. However, in order to approximate the thrust of the airplane, a large intermediate rocket is currently being used. A photograph of this rocket is shown in figure 6. The magnitude and duration of the rocket thrust for two of the large intermediate model rockets are shown in figure 7. The curves are fairly similar and indicate good repeatability of firings. The average value of the thrust appears to be about 10 ounces for about 5 seconds. Based on the test altitude and scale of the model, this value of thrust and time duration converted to full scale is about 3,600 pounds for 25 seconds.

Wind Tunnel and Testing Technique

The tests of the dynamic model were conducted in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that of the Langley 15-foot free-spinning tunnel which is described in reference 4 except that the technique in launching the model has been changed. With the controls set in the desired position, the model is now launched by hand with rotation into the vertically rising airstream. After a number of turns in the established spin, recovery is normally attempted by movement of one or more controls by means of a remote-control mechanism installed in the model. After recovery the model dives into a safety net. For the current investigation, the remote-control mechanism was used only to activate the rockets.

For the rocket spin-recovery tests, the controls on the model were set in such a manner as to be most conducive in maintaining the spin of the model since an emergency spin-recovery device must effect a recovery regardless of the position of the controls. The control settings, which were determined on the basis of another investigation of the free-spinning characteristics of this same model, were rudder full with the spin and ailerons full against the spin; there was little effect of horizontal-tail position and for the present investigation a neutral setting was arbitrarily used.

To attempt a spin recovery the rockets were fired while the controls remained fixed; thus the recovery was due entirely to the action of the rockets. Each test was made at least twice as a check on the results. The turns for recovery were measured from the time the rocket was fired to the time the spin rotation ceased. Recovery characteristics of the model were considered satisfactory if recovery from the spin occurred in $2\frac{1}{4}$ turns or less. This criterion was used on the basis of a correlation of available full-scale airplane spin-recovery data and corresponding model-test results. The results of model tests were converted to corresponding full-scale values by methods described in reference 4.

TEST CONDITIONS

The model was ballasted to obtain dynamic similarity to the airplane at an altitude of 30,000 feet (ρ = 0.000889 slug/cu ft). Installation of the rockets on the model was accompanied by a proper shifting of weights in order not to alter the normal-mass characteristics of the airplane which were being simulated. The mass characteristics and inertia parameters of the airplane for the fighter take-off loading (with guns and normal fuel) condition and the loadings tested on the model are shown in table II. All tests were conducted with the model in the clean condition (cockpit closed, flaps neutral, and landing gear retracted) and generally with the rockets installed. Brief tests were performed with and without rockets installed on the model to determine whether any aerodynamic interferences were present.

Yaw Rockets

For the test conditions where an antispin yawing moment was applied to the model, two different locations of the small rockets (3 ounces of thrust for 2 seconds) were tested. For one condition, the rockets were mounted on the wing tips so that their thrust was perpendicular to the Z body axis and thus provided an antispin yawing moment about this axis. When one rocket was fired, an antispin yawing moment (C_n = 0.045) equal to 20,138 foot-pounds, full scale, was applied; firing both rockets simultaneously produced an antispin yawing moment (C_n = 0.090) equal to 40,276 foot-pounds, full scale. For the other condition, the rockets were mounted in the fuselage near the nose of the model (figs. 2 and 3) at various distances from the model center of gravity so that their thrust again provided an antispin yawing moment of various magnitudes about the Z body axis. The different locations of the rockets in the fuselage are designated as positions 1, 2, and 3 with position 1 being the farthest from the model center of gravity (figs. 2 and 3). An antispin yawing moment (C_n = 0.051) equal to 22,717 foot-pounds, full scale, was applied when the nose rocket in position 2 was fired; when the nose rockets in positions 2 and 3 were fired simultaneously, an antispin yawing moment ($C_n = 0.098$) of 43,580 foot-pounds, full scale, was applied. Firing all three nose rockets simultaneously (positions 1, 2, and 3) produced an antispin yawing moment ($C_n = 0.152$) equal to 68,105 foot-pounds, full scale. These rockets were fired singularly and in combination.

Thrust-Simulation Rocket

The large rocket used to simulate the thrust of the airplane jet engine was mounted in the tail of the model with the line of thrust parallel with the fuselage reference line and passing through the center of gravity. As previously stated, the scaled-up model thrust was equal to about 3,600 pounds.

Roll Rockets

For a few brief exploratory tests in which a rolling moment was applied about the X body axis, small rockets were mounted at the wing tips with the rocket thrust perpendicular to the wing-chord plane.

PRECISION

The spin-tunnel results presented herein are believed to be the true values for the model within the following limits:

α, deg	± 1
ϕ, deg	± 1
V, percent	± 5
Ω, percent	± 2
Turns for recovery:	
When obtained from motion-picture records	$\pm 1/4$
When obtained by visual estimate	$\pm 1/2$

Comparison between model and full-scale results in reference 5 indicated that model tests satisfactorily predicted full-scale recovery characteristics by rudder reversal approximately 90 percent of the time and that, for the remaining 10 percent of the time, the model results were of value in predicting some of the details of the full-scale spins. The airplanes generally spun at an angle of attack closer to 45° than did the corresponding models. The comparison presented in reference 5 also indicated that generally the airplane spun with the inner wing tilted more downward and with a greater altitude loss per revolution than did the corresponding model, although the higher rate of descent was found to be generally associated with the smaller angle of attack regardless of whether it was for the model or the airplane.

Because it is impracticable to ballast the model exactly and because of inadvertent damage to the model during tests, the measured weight and mass distribution of the model varied from the true scaled-down values by the following:

Weight, percent	0
Center-of-gravity location, percent $\bar{c}$	4 rearward
Moments of inertia:	
I_X, percent	4 low
I_Y, percent	1 low
I_Z, percent	0

The accuracy of measuring the weight and mass distribution of the model is believed to be within the following limits:

Weight, percent	± 1
Center-of-gravity location, percent $\bar{c}$	± 1
Moments of inertia, percent	± 5

Controls were set with an accuracy of $\pm 1^{\circ}$.

RESULTS AND DISCUSSION

The results of this investigation are presented in graph and film-strip form (figs. 8 and 9). In addition, the results of the investigation are presented in table III along with results of spin-recovery tail-parachute tests obtained from a separate investigation. Results for right and left spins were fairly similar; the film strips of the model motion arbitrarily show the model spinning to the left. As previously indicated, model data are in terms of the full-scale values for the corresponding airplane at a test altitude of 30,000 feet. In converting the moments produced by the rockets to coefficient form, the air density at the spin-test altitude and the rate of descent of the model in the steady-spin condition were used. Brief spin tests performed on the model with and without rockets indicated no differences in the steady-spin characteristics; thus the aerodynamic effects of the rockets were considered small. As previously mentioned, the spin and recovery characteristics of this model by control manipulation are being investigated separately in the Langley 20-foot free-spinning tunnel. The results of this investigation indicate that for both loading conditions under which the model was tested and for the control setting most conducive for spinning (the same setting used for the rocket-recovery tests in the present investigation) the model spun fairly steadily at a high angle of attack (83°) with the wings nearly level and would not recover by normal-control movements.

Yaw Rockets

Wing tip.- With the rudder full with the spin, the all-movable horizontal tail neutral, and the ailerons full against the spin, recovery tests were made to determine the effectiveness of yaw rockets attached to the wing tips. When one wing-tip rocket was fired, the recoveries were unsatisfactory. However, satisfactory recoveries ranging from about 1 to $1\frac{1}{2}$ turns were obtained when both left and right wing-tip rockets were fired simultaneously. The motion of the model after both rockets had been fired simultaneously was a fairly smooth transition from the steady-spin condition to the recovery dive, the rate of rotation slowing down as the model pitched down to a low angle of attack while remaining erect. A film strip showing the model recovering from a left spin by firing both rockets simultaneously is presented in figure 8.

Nose.- When the rocket installed in the fuselage near the nose (position 2) was fired, the spin recoveries were marginal. However, firing nose rockets simultaneously in positions 2 and 3 produced satisfactory recoveries ranging from $\frac{1}{2}$ to $1\frac{1}{2}$ turns. The recovery motion was similar to the motion produced when both wing-tip rockets were fired simultaneously in that the recovery motion was a smooth transition from the steady spin through the recovery dive. When all three nose rockets (positions 1, 2, and 3) were fired simultaneously, rapid recoveries of $\frac{1}{2}$ turn were obtained. However, although the model stopped spinning in the original direction abruptly when the rockets were fired, as a result of the excess rocket thrust, the model quickly went into a spin in the opposite direction without changing its pitch attitude. This result is similar to a result reported in reference 2 where a full-scale airplane recovered from a right spin by use of yaw rockets and then entered a left spin because of excess rocket thrust. Thus the danger of having too much rocket thrust should be considered when determining the size of rocket needed for spin recovery. Some means of dumping the excess thrust should be provided.

A plot of the yawing-moment coefficients provided by the nose and wing-tip rockets against the turns for recovery is shown on figure 9. The turns for recovery in this figure are representative results of the test conditions. The results, as would be expected, indicated that, as the antispin yawing-moment coefficient C_n was increased, the turns for recovery decreased. The results did not vary linearly in that, as C_n was decreased from a value of 0.15 to 0.08, there was only a small increase in the turns for recovery; however, below a value of C_n of approximately 0.08 the turns for recovery increased sharply as C_n was decreased. It appears that, based on these results, a yawing-moment coefficient greater than 0.08 and less than 0.13 must be provided against the spin in order to effect satisfactory recoveries for this particular airplane and mass loading. As a further check, the results of spin-recovery tail-parachute tests conducted on this model in another investigation at the Langley Laboratory are presented. The size of parachute recommended in that investigation produced satisfactory recoveries ranging from $1\frac{1}{4}$ to $1\frac{3}{4}$ turns. The yawing-moment coefficient against the spin provided by this size of parachute was calculated to be 0.124. This point was plotted in figure 9 and showed fairly good agreement with the results produced by the rockets.

Cognizance was taken of the fact that when the rockets were fired on the model so as to produce a yawing moment, small secondary moments were applied about the model center of gravity; no attempt was made to eliminate these secondary moments since they would also be present on a full-scale airplane if rockets were fired at corresponding locations as on the model. In any case, these effects were considered small.

The Chance Vought Aircraft, Inc., evidenced interest in the possibilities of installing in the fuselage a 2,000-pound thrust yaw rocket with a thrust duration of 20 seconds approximately 18 feet ahead of the airplane center of gravity to be used as an emergency spin-recovery device. The antispin yawing moment produced by such a rocket would be 36,320 foot-pounds; the antispin yawing-moment coefficient based on this value of the yawing moment would be 0.081. By referring to figure 9, it appears that for this value of C_n the airplane should recover satisfactorily.

Thrust-Simulation Rocket

Only very meager results are available on the effect of thrust application on the spin-recovery characteristics of airplanes since very few tests have been performed in the past. For the present investigation, the thrust of the jet engine and afterburner was simulated; the gyroscopic effects produced by the rotating parts of the engine were not simulated because of practical considerations. However, unpublished data indicate that the gyroscopic effects of some jet engines may be large enough to retard or aid spin recoveries depending on the direction of the spin.

As mentioned previously, in order to simulate the effect of engine thrust on the recovery characteristics of the model, a large rocket was installed in the tail of the model and fired. Generally, the thrust did not have an appreciable effect on the spin characteristics of the model, although there was a slight increase in the rate of rotation of the model. No recovery was indicated. Although these results are not considered to be conclusive inasmuch as the model thrust was less than desired, the results can be considered as a first approximation of what might be expected for this particular airplane.

Roll Rockets

Brief exploratory tests have been made with roll rockets attached to the wing tips of the model and the results indicated that applying a sufficient rolling moment may be effective in terminating the spin. To date, however, the results have indicated that the effectiveness of this technique for the XF8U-1 model may be critically associated with variations in mass distribution and corresponding rates of rotation in the spin.

CONCLUSIONS

Based on the results of rocket spin-recovery tests and tests simulating the effect of engine thrust on a 1/25-scale model of the Chance Vought XF8U-1 airplane in the clean condition at an equivalent spin altitude of 30,000 feet, the following conclusions are made:

1. Satisfactory spin recoveries from erect spins were indicated by the application of an antispin yawing moment (yawing-moment coefficient of 0.08) of at least 35,730 foot-pounds, full scale, and not greater than an antispin yawing moment (yawing-moment coefficient of 0.13) of 58,060 foot-pounds, full scale, by either rockets attached to the wing tips or installed in the fuselage ahead of the model center of gravity; the rocket thrust duration used was equivalent to 10 seconds, full scale.

2. Simulation of engine thrust did not aid recovery and may have been slightly detrimental.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
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2. Burk, Sanger M., Jr., and Healy, Frederick M.: Comparison of Model and Full-Scale Spin Recoveries Obtained by Use of Rockets. NACA TN 3068, 1954.

3. Burk, Sanger M., Jr., and Healy, Frederick M.: Free-Spinning-Tunnel Investigation To Determine the Effect of Spin-Recovery Rockets and Thrust Simulation on the Recovery Characteristics of a 1/21-Scale Model of the Chance Vought F7U-3 Airplane. TED No. NACA AD 3103, NACA RM SL55A04, Bur. Aero., 1955.

4. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. NACA Rep. 557, 1936.

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TABLE I.- DIMENSIONAL CHARACTERISTICS, MAXIMUM CONTROL DEFLECTIONS,

AND POWERPLANT OF THE CHANCE VOUGHT XF8U-1 AIRPLANE

Overall length, ft	54.02
Wing:	
Span, ft	35.66
Area (including fixed chord-extension), sq ft	385.33
Root chord, in.	201.98
Tip chord (not including chord-extension), in.	49.92
Tip chord (including chord-extension), in.	56.18
$\bar{c}$, in.	141.25
Leading edge of $\bar{c}$ rearward of leading edge of root chord, in.	92.5
Aspect ratio (area includes chord-extension)	3.32
Taper ratio (not including chord-extension)	0.25
Taper ratio (including chord-extension)	0.28
Dihedral, deg	-5
Sweepback at c/4, deg	42
Incidence, deg	-1
Airfoil section:	
Root	NACA 65A006
Tip	NACA 65A005
Ailerons:	
Total area, sq ft	40.70
Span, percent b/2	39.80
Horizontal tail:	
Span, ft	19.25
Area (extended to fuselage center line), sq ft	108.99
Sweepback at c/4, deg	45
Root chord, in.	114.80
Tip chord, in.	17.20
Aspect ratio	3.40
Dihedral, deg	5.42
Airfoil section:	
Root	Mod. NACA 65A006
Tip	Mod. NACA 65A004
Vertical tail:	
Height, ft	12.08
Total area (not including dorsal; area extends from fuselage center line), sq ft	105.49
Rudder area, sq ft	13.48
Sweepback at c/4, deg	45.0
Root chord, at fuselage center line, in.	157.50
Tip chord, in.	41.00
Aspect ratio	1.38
Airfoil section:	
Root	Mod. NACA 65A006
Tip	Mod. NACA 65A004
Tail-damping-power factor	0
Powerplant:	
Engine designation	one P&W J57 (afterburner)
Total thrust (including afterburner), lb	14,500
Normal maximum control deflections:	
Rudder, deg	±6
Ailerons, deg	±15
Elevator, deg	30 up, 10 down

TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADING USED ON THE CHANCE VOUGHT XF8U-1 AIRPLANE AND FOR LOADINGS TESTED ON THE 1/25-SCALE MODEL

[Model values are given as corresponding full-scale values; moments of inertia are given about the center of gravity.]

Loading	Weight, lb	Center-of-gravity location		Relative density μ		Moments of inertia, slug-feet^2			Mass parameters		
		$x/\bar{c}$	$z/\bar{c}$	Sea level	30,000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane values											
Fighter with guns and normal fuel take-off	23,670	0.227	0.026	23.02	61.61	13,591	85,141	92,430	-765×10^{-4}	-78×10^{-4}	843×10^{-4}
Model values											
Fighter with guns and normal fuel take-off	23,771	0.219	0.024	23.11	61.86	13,018	84,369	92,230	-755×10^{-4}	-83×10^{-4}	838×10^{-4}
Fighter with guns and normal fuel take-off (center of gravity moved rearward)	24,208	.283	.022	23.55	63.03	13,346	78,177	87,174	-673×10^{-4}	-93×10^{-4}	766×10^{-4}

TABLE III.- THE EFFECT OF SPIN-RECOVERY ROCKETS AND TAIL PARACHUTES ON THE RECOVERY CHARACTERISTICS OF A 1/25-SCALE MODEL OF THE CHANCE VOUGHT XF8U-1 AIRPLANE

[Data have been converted to full-scale values]

Location of yaw rockets and parachutes	Force, lb	Antispin yawing moment, ft-lb	Antispin yawing-moment coefficient, C_n	Turns for recovery
Outer wing tip (right wing tip)	1,085	20,138	0.045	$3\frac{1}{4}$, [a]$>2\frac{3}{4}$
Right and left wing tips	2,170	40,276	.090	1, $1\frac{1}{2}$
One rocket in nose, position 2	1,085	22,717	.051	$2\frac{1}{4}$, $2\frac{1}{2}$
Two rockets in nose, positions 2 and 3	2,170	43,580	.098	$\frac{1}{2}$, $\frac{1}{2}$, $1\frac{1}{2}$
Three rockets in nose positions 1, 2, and 3	3,255	68,105	.152	$\frac{1}{2}$, $\frac{1}{2}$
Tail parachute[b]	[c]1,720	36,464	.124	$1\frac{1}{4}$, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, $1\frac{1}{4}$, $1\frac{1}{2}$

[a]Model struck safety net in recovering from spin; recovery appeared to be almost completed.

[b]Results obtained from a separate investigation

[c]Component of the parachute drag force that applies a yawing moment about the Z body axis.

[redacted]

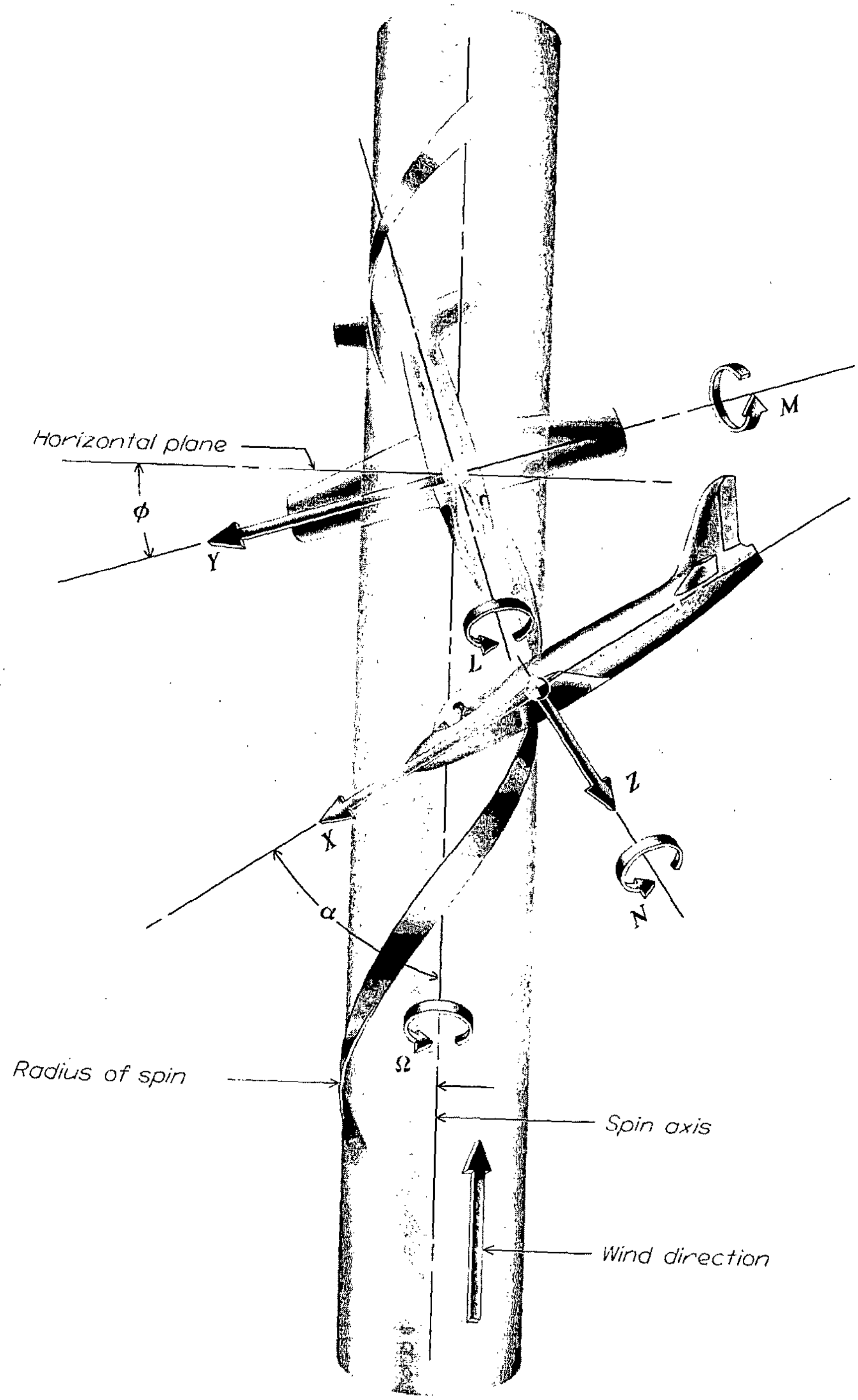

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Figure 1.- Illustration of an airplane in a spin. Arrows indicate positive directions of forces and moments along and about the body axes of the airplane.

[redacted]

 [redacted]

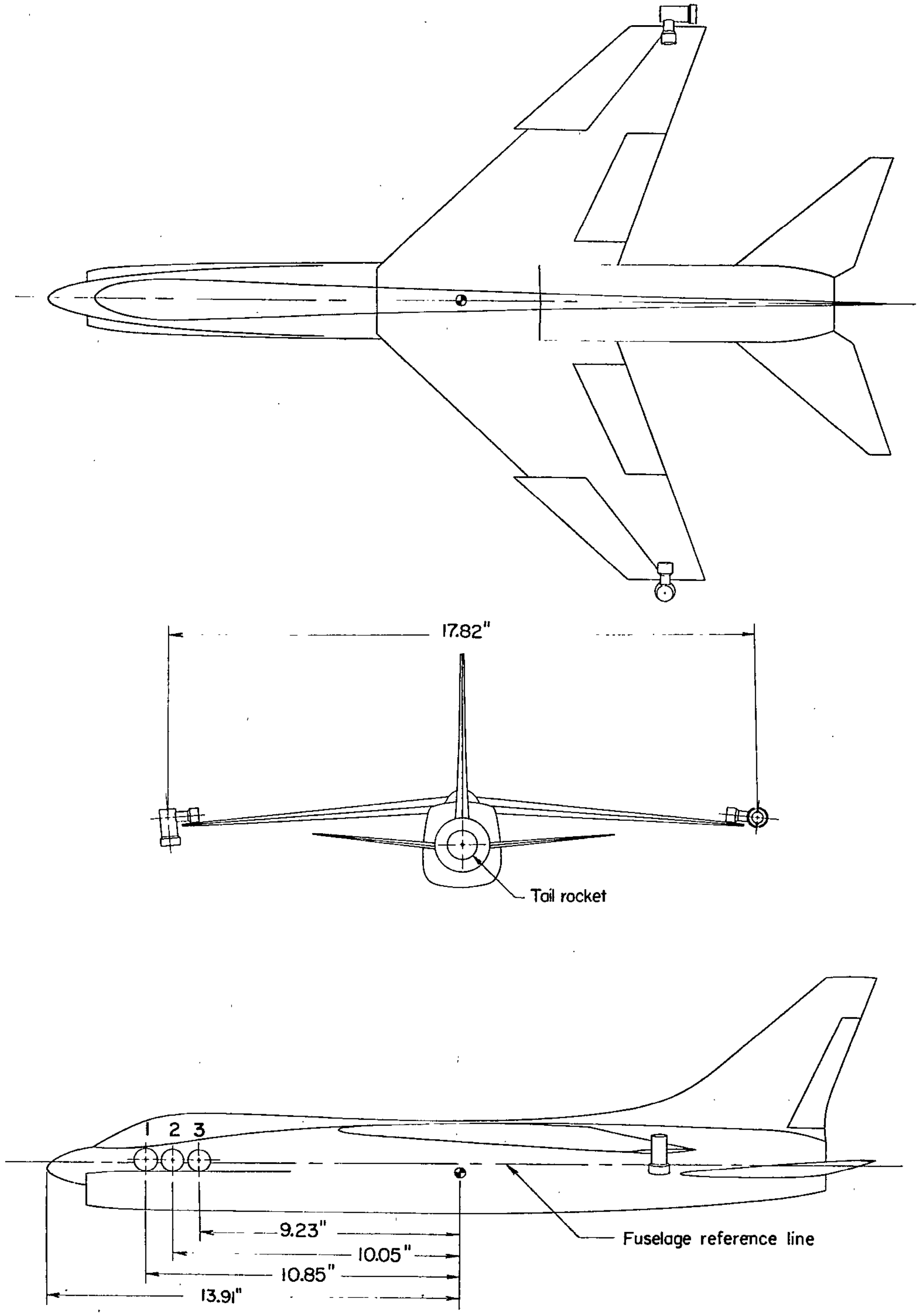
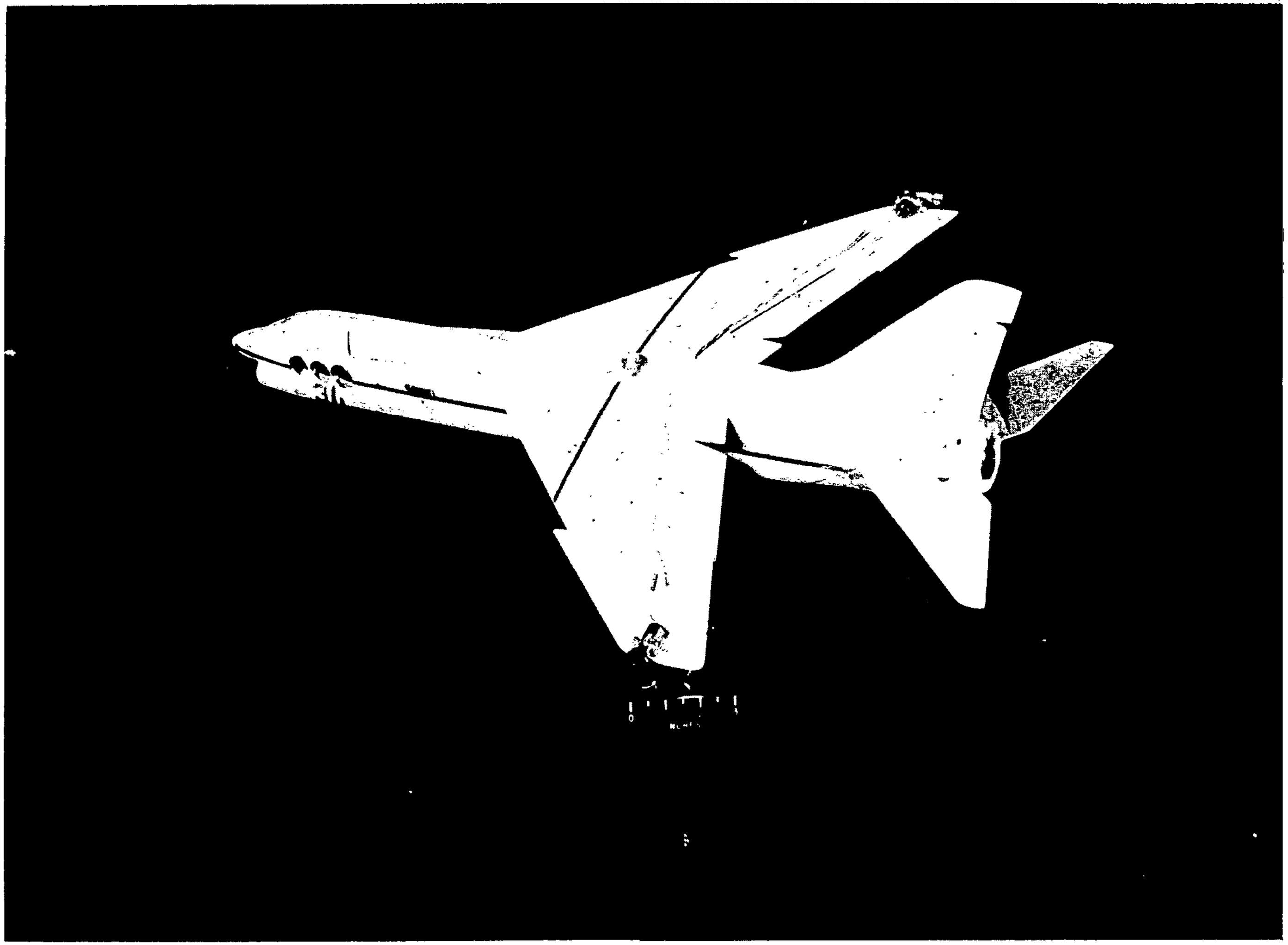


Figure 2.- Three-view drawing of the 1/25-scale model of the Chance Vought XF8U-1 airplane with rockets installed. Dimensions are model values. Center-of-gravity position shown is for the fighter take-off loading (with guns and normal fuel).

[redacted]



L-86729

Figure 3.- Photograph of the 1/25-scale model of the Chance Vought XF8U-1 airplane with rockets installed.

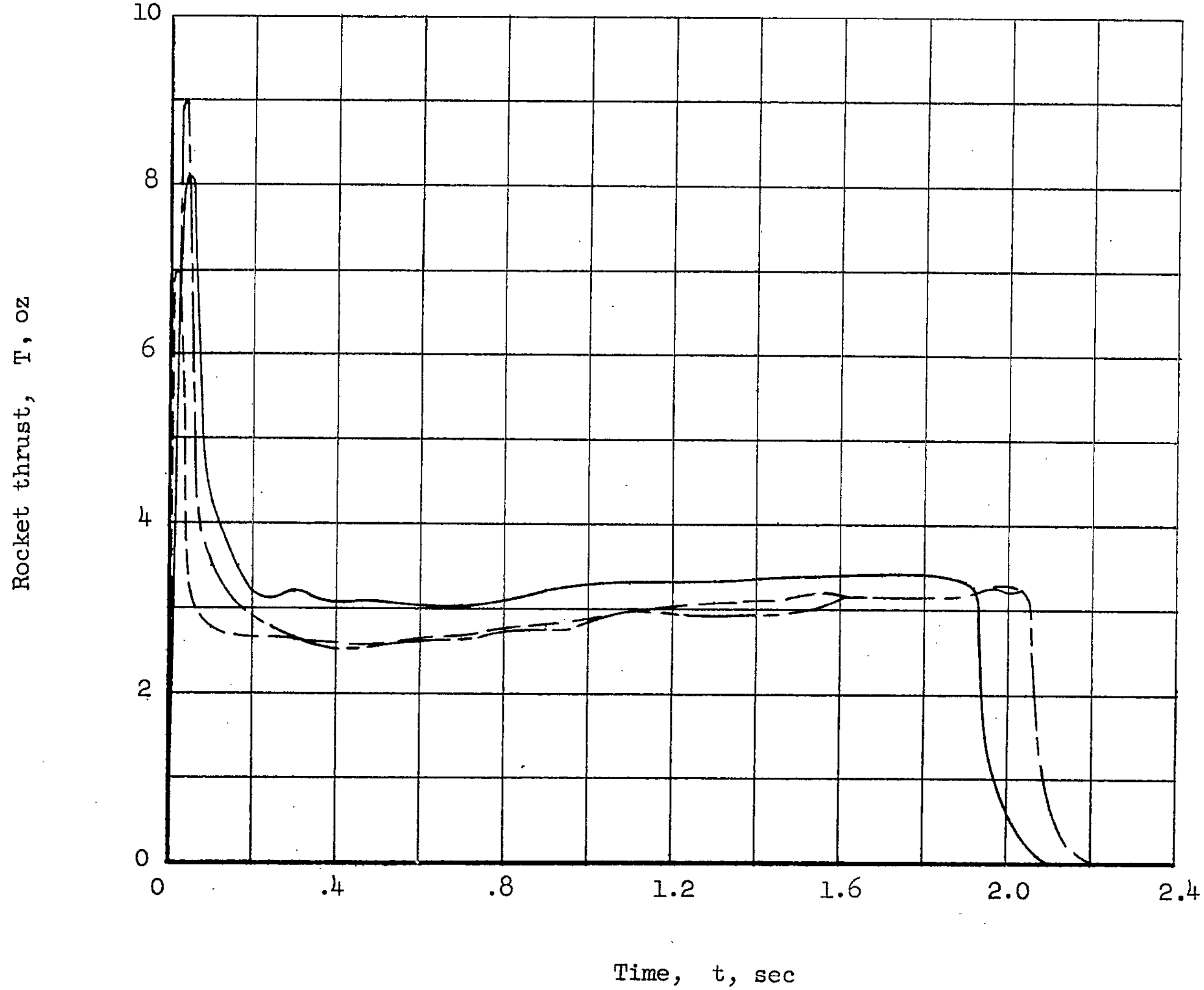


Figure 4.- Variation of thrust of small model rocket with time for several rocket tests showing repeatability of firings.

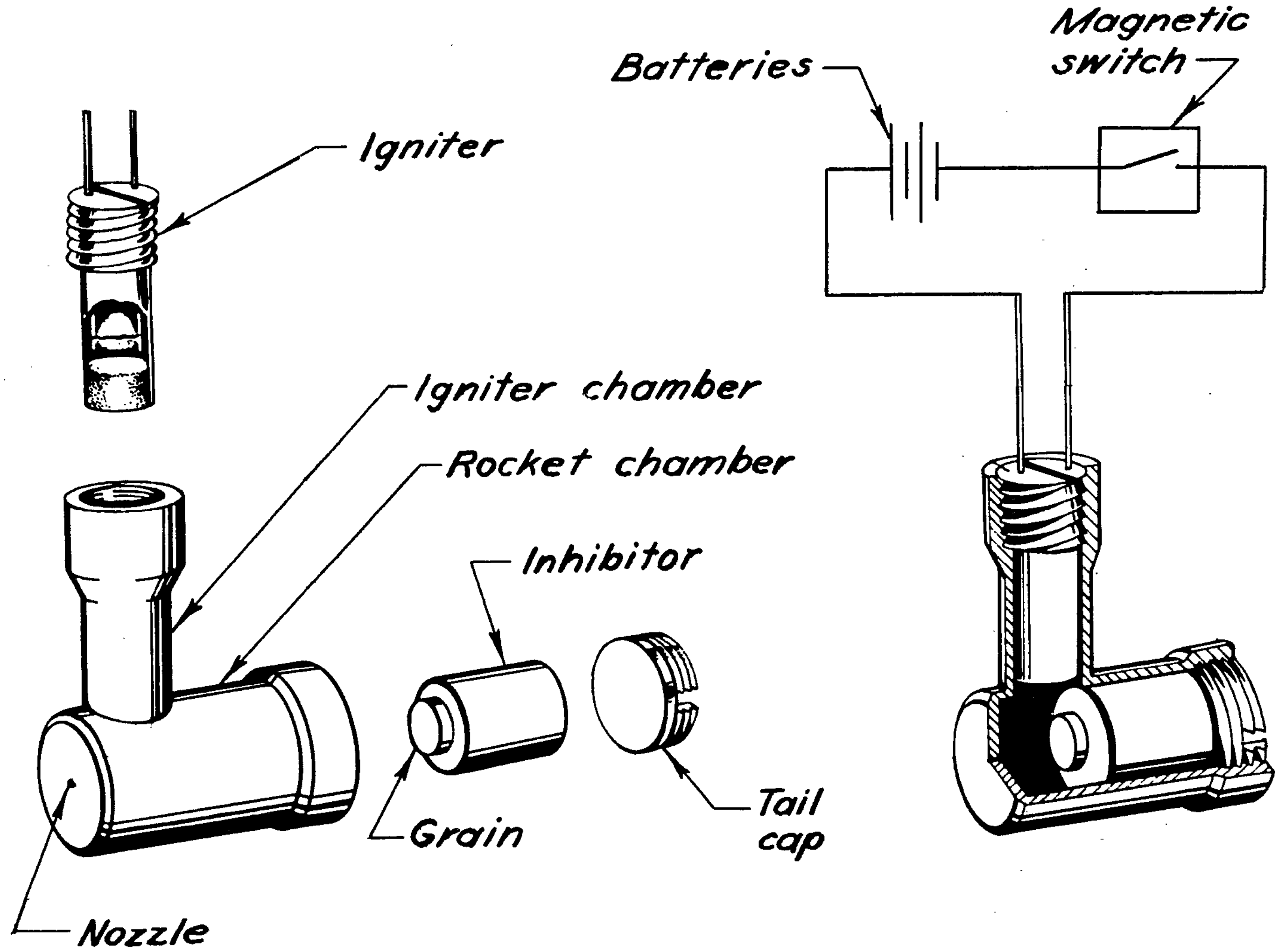


Figure 5.- Sketch of small model rocket showing the various parts including the electrical circuit.

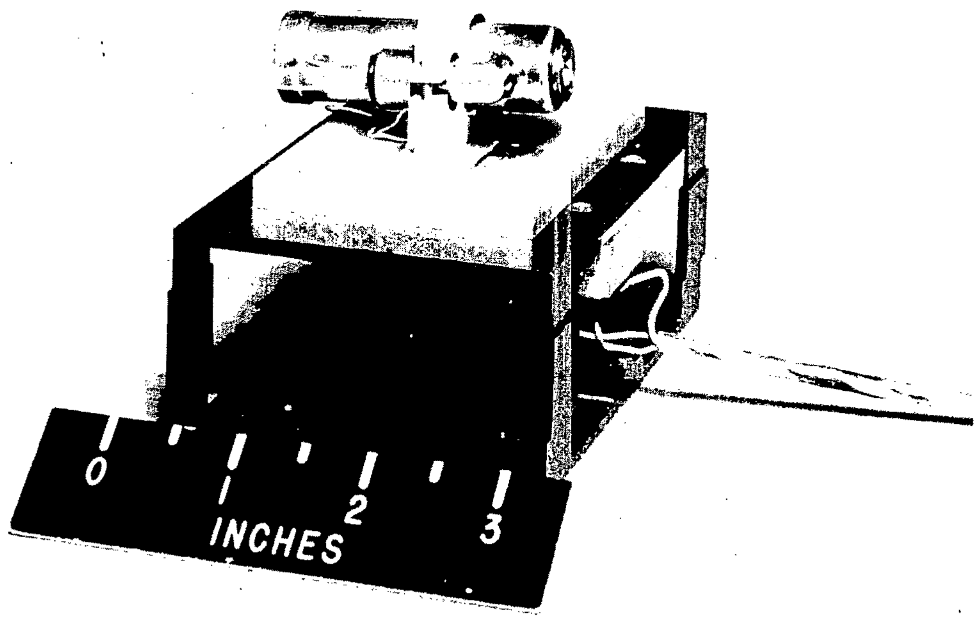


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Figure 6.- Photograph of the large intermediate model rocket (mounted on test stand) used to simulate the effect of thrust on the 1/25-scale model of the Chance Vought XF8U-1 airplane.

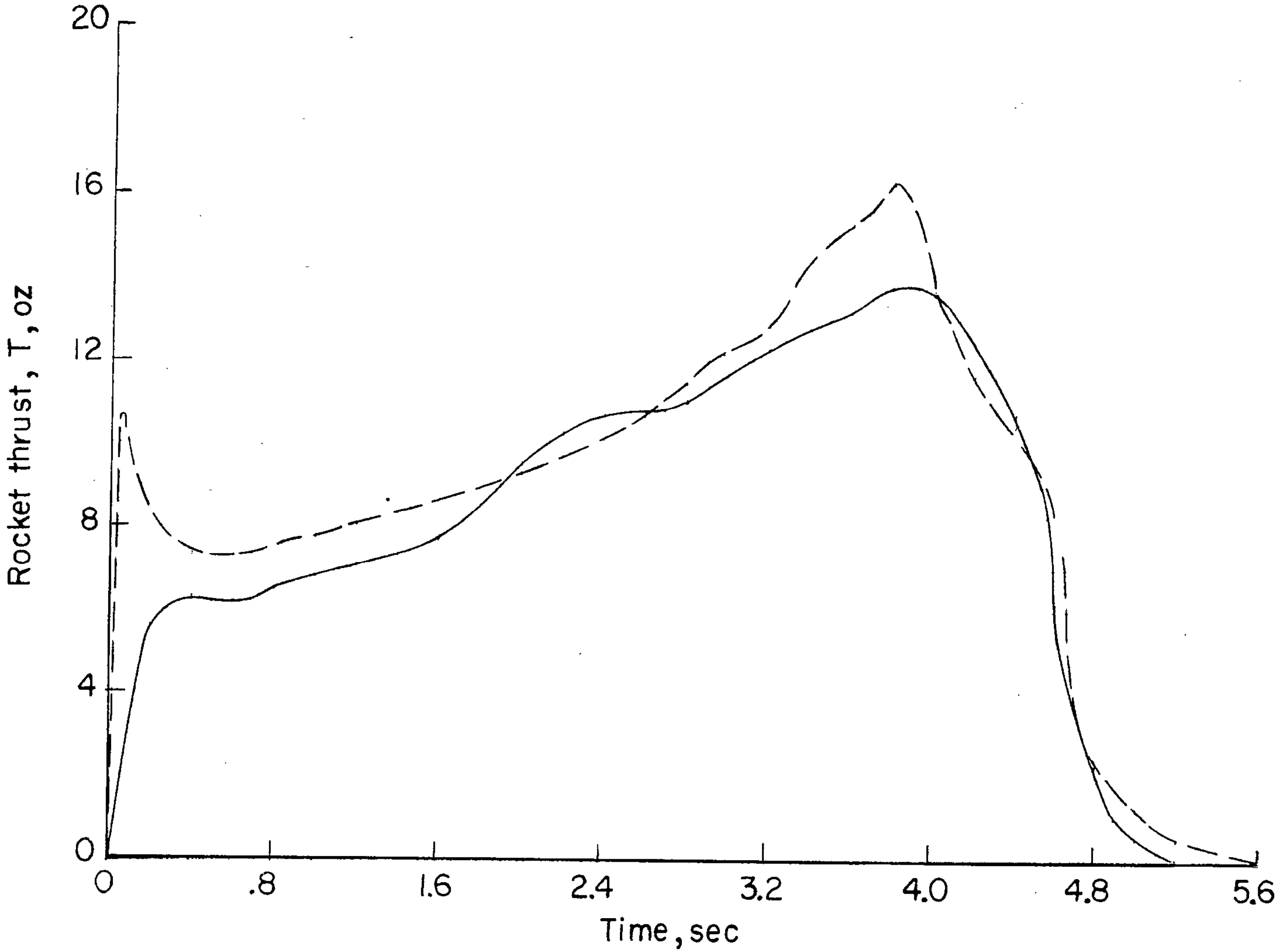

Figure 7.- Variation of thrust of large intermediate model rocket with time for two rocket tests showing repeatability of firings.

[redacted]

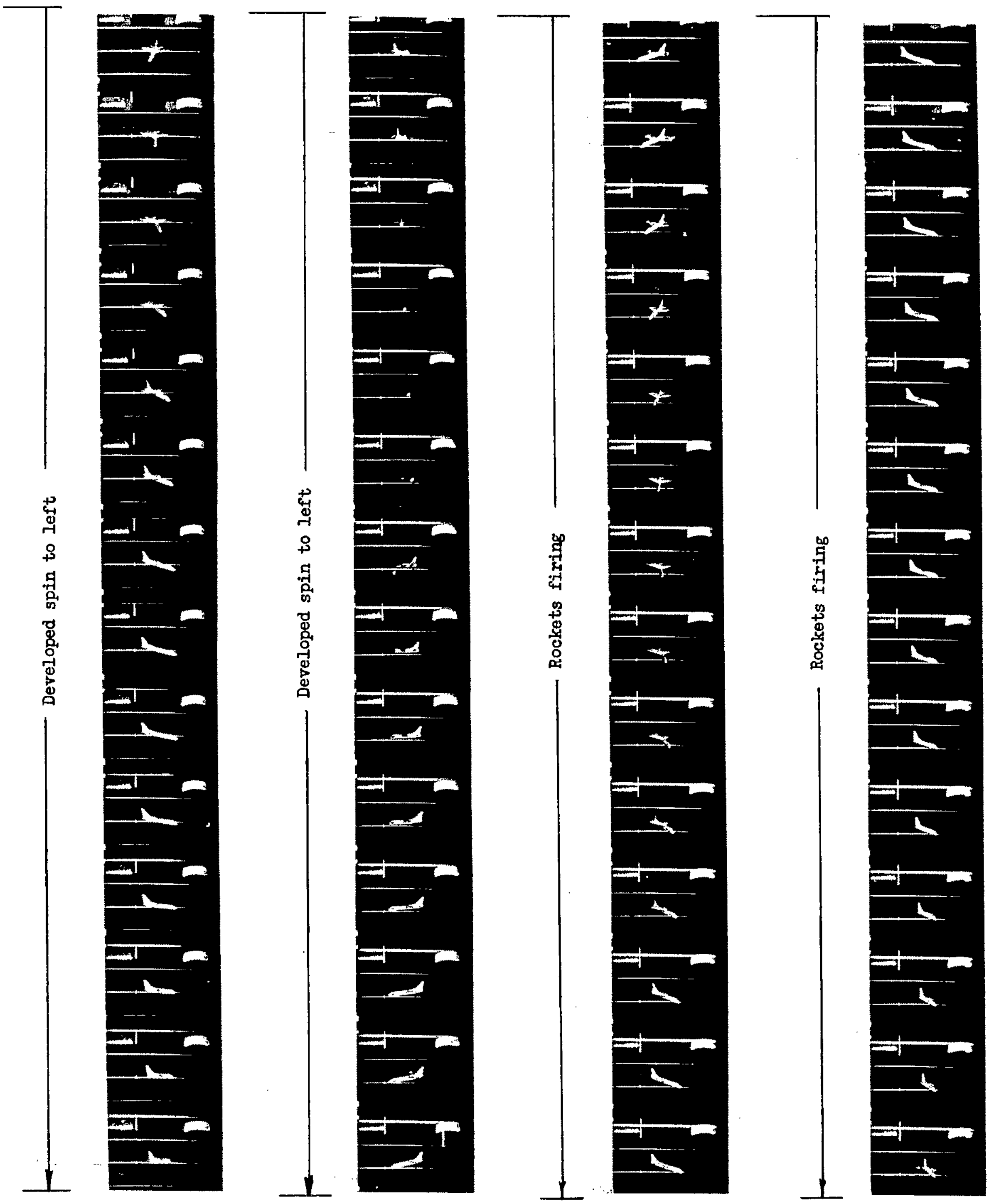

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Figure 8.- Typical motion of a 1/25-scale model of the Chance Vought XF8U-1 airplane recovering from a left spin by firing simultaneously both left and right wing-tip yaw rockets. Film speed 64 frames per second.

[redacted]

[redacted]

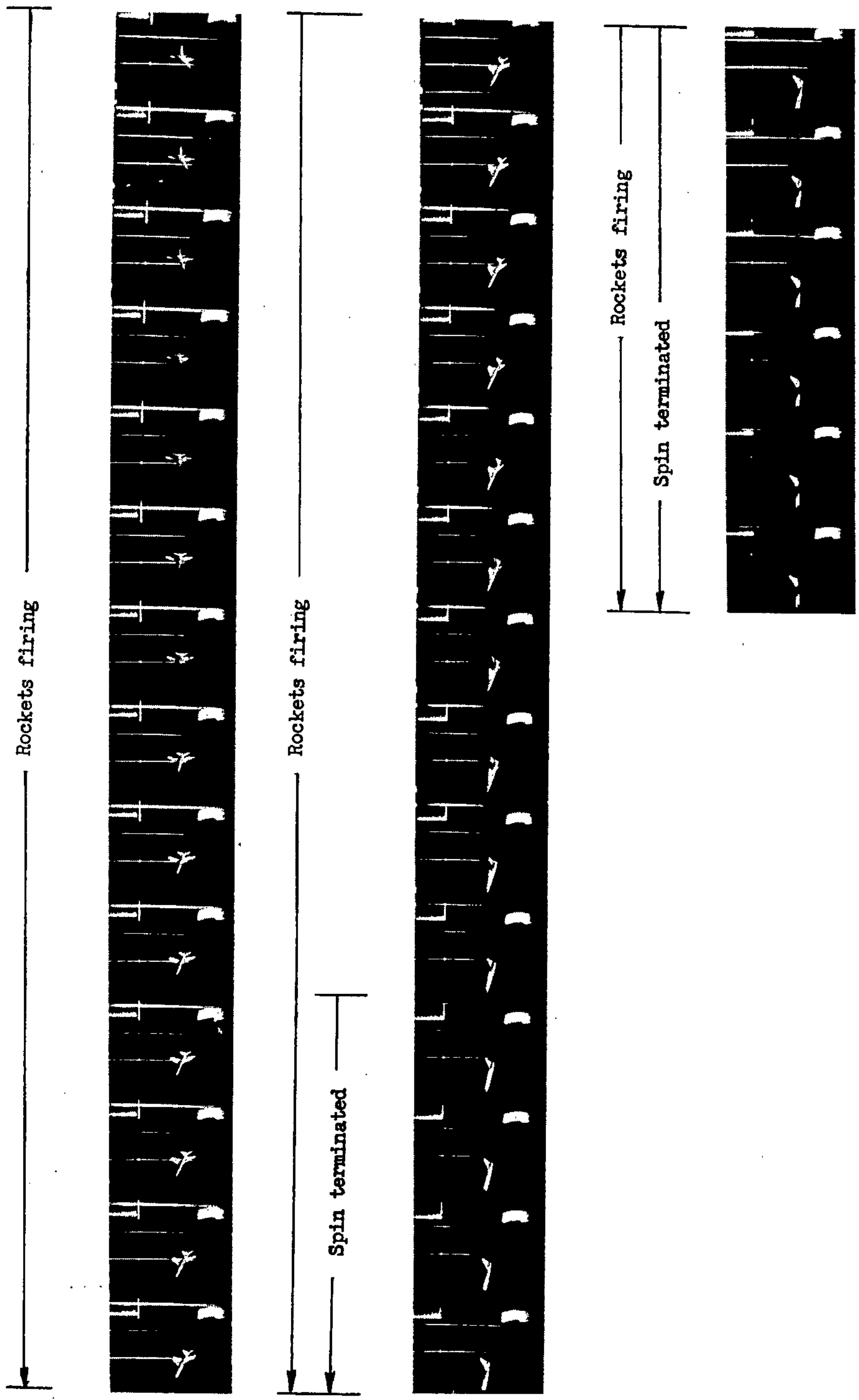

Figure 8.- Concluded.

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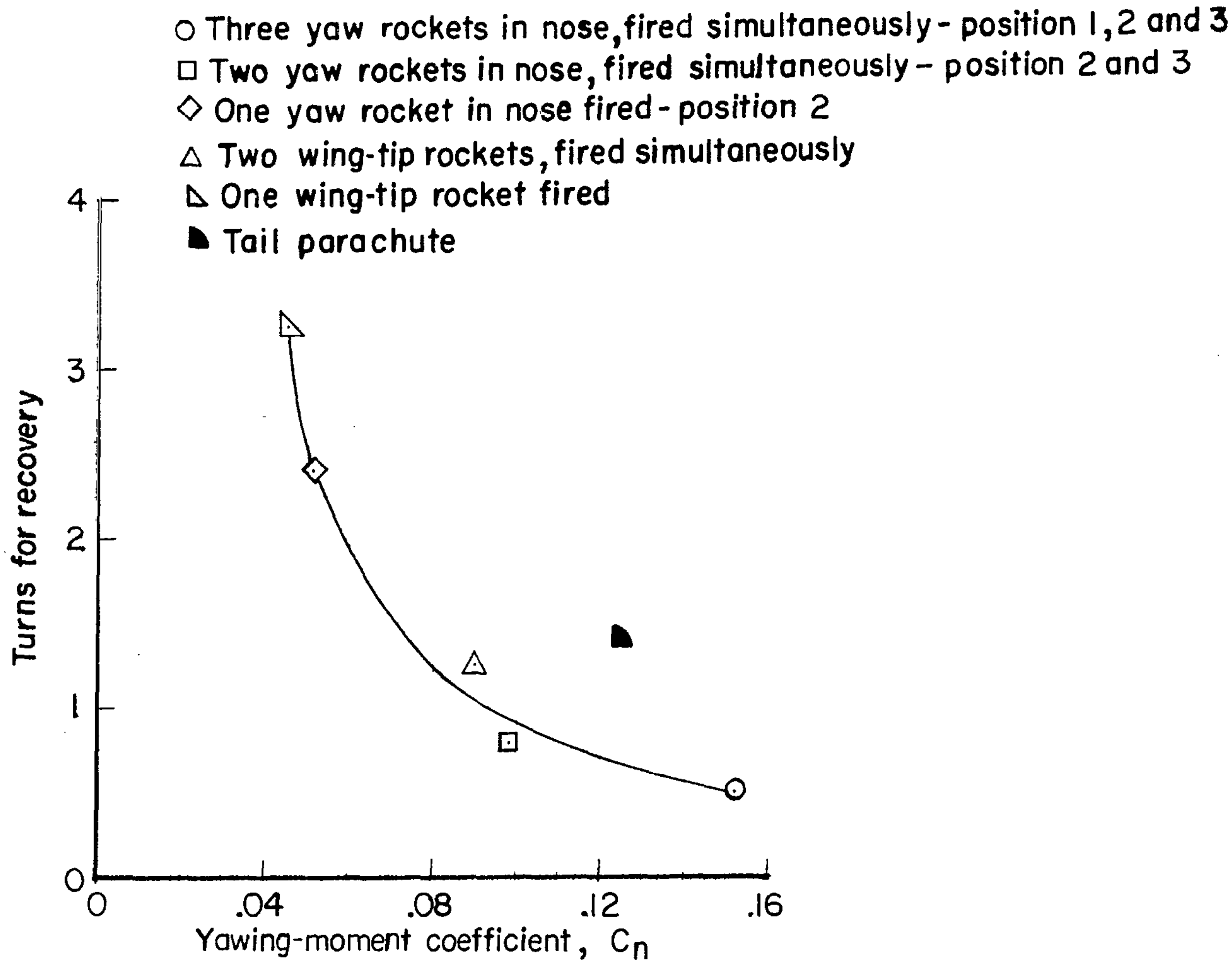

Figure 9.- Effect of varying the yawing-moment coefficients provided by spin-recovery rockets on the number of turns for recovery on the 1/25-scale model of the Chance Vought XF8U-1 airplane.